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The Impact of Smoke From Vegetation Fires on Sensory Characteristics of Cabernet Sauvignon Wines Made From Affected Grapes

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The increased incidence of vegetation fires near vineyards in the Western Cape, South Africa has led to growing concern over smoke taint in wine made from affected grapes. This study focused on the sensory properties of wines made from grapes that have been exposed to bushfire smoke. Cabernet Sauvignon grapes (ten days' post-véraison) were exposed to a single, hour-long treatment with smoke from burning fynbos under controlled conditions. The grapes were allowed to ripen and wines were then produced. Descriptive analysis of the wines was done for aroma and taste attributes. The results of the investigation show that the exposure of grapes to smoke during ripening led to sensory differences between wines made from different treatments, and that wines made from smoke-exposed grapes were perceived as having 'burnt', 'smoky' aromas and an 'ashy' aftertaste. Despite levels of free volatile phenols (VPs) being below or close to odour threshold levels for individual phenols, their combination led to a perception of the so-called 'burnt rubber' taint perceived in some South African red wines.

INTRODUCTION

In recent years, the frequency of vegetation fire in the Western Cape, South Africa has led to concern about smoke taint in wines made from the affected grapes (Hesseling, 2013). Bushfires are seldom hot enough or supplied with enough oxygen for complete combustion of plant biomass to occur. Low molecular mass and highly volatile compounds, including phenols, are formed under flaming conditions (Kelly *et al*., 2012). While vegetation fires are not unique to South Africa, the flora found in the Western Cape is different from that in any other region in which grapevines are grown, as fynbos plantations are often adjacent to vineyards (Cowling *et al*., 2009). Although very little research has been done to characterise the aroma profile of fynbos (the local name for the indigenous floral kingdom), various species are well known for being very pungent and aromatic. Fynbos species are often small, multi-stemmed shrubs with persistent rootstock, which enables the plants to re-sprout after fire. Chemically stimulated germination of the seeds triggered by smoke and/or charred wood has also been found to be important in fynbos (Bond & Keeley, 2005). The effect of burning fynbos, and the sensory properties of the smoke produced, have not yet been assessed in any context. Investigations in Australia have established that wine produced from grapes exposed to smoke from bushfires develop objectionable smoky, ashy and burnt characters (Kennison *et al*., 2008; Sheppard *et al*., 2009; Hayasaka *et al*., 2010; Singh *et al*., 2011). Guaiacol and 4-methylguaiacol (4-MG) have been used as key indicators of smoke exposure and potential taint formation (Kennison *et al*., 2007; Sheppard *et al*., 2009). More recently, studies have demonstrated that additional volatile phenolic compounds (cresols, phenols and syringols) may account for taint characteristics in smoke-affected wines (Kelly *et al*., 2012; 2014; Parker *et al*., 2012).

Sheppard *et al*. (2009) reported that methoxyphenols (including guaiacol and 4-MG) arise from the partial pyrolysis of lignin and are key contributors to the aroma of wood smoke. This is supported by Kelly *et al*. (2012), who also found that, regardless of vegetation fuel type, the compounds guaiacol and 4-MG represented roughly 20% of the total phenols found in smoke-tainted wines.

Once VPs are taken up by grapes, they are rapidly metabolised into their more stable glycosidic forms (Hayasaka *et al*., 2010; Singh *et al*., 2011; Parker *et al*., 2012). These glycoconjugated precursors may hydrolyse during the fermentation, ageing and storage of wine to release free volatile phenols (Kennison *et al*., 2008; Hayasaka *et al*., 2013). Parker *et al*. (2012) also noted increases of 15 to 20 µg/L of volatile phenols released from glycosylated precursors in the mouth during tasting. This release may

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be enough to increase VP levels above odour-detection thresholds, which may explain the findings by Panzeri (2013) and Van Zyl (2013), namely that wines displayed 'burnt rubber' characteristics on tasting, despite VPs being present at levels below their odour thresholds.

Winemaking practices that reduce grape skin contact have been shown to limit the extraction of guaiacol glycosides, resulting in reduced smoky aroma and flavour characteristics (Ristic *et al*., 2011; Kelly *et al*., 2014). However, glycosylated precursors may also be present in the flesh of severely exposed grapes (Singh *et al*., 2011), and even the free-run juice of smoke-tainted grapes can contain high levels of 4-MG and guaiacol (Kennison *et al*., 2008).

The aim of this study was to investigate the impact of smoke on wines made from grapes near smoke from burning fynbos. In this study, experimental wines from the 2012 vintage were subjected to sensory analysis in order to determine whether or not wines made from fynbos smoke-affected grapes acquired a smoke taint and/or 'burnt rubber' (BR) characteristics.

MATERIALS AND METHODS

Layout of vineyards

The smoke treatment was carried out during both the 2012 and 2013 growing seasons. The study was conducted on a *Vitis vinifera* L. cv. Cabernet Sauvignon clone CS 388C, grafted onto 101-14 Mgt (*Vitis riparia* x *Vitis rupestris*). Thirteen plots were selected randomly, each containing three adjacent vines. Experimental vine plots were exposed to smoke in purpose-built greenhouse-type structures, as described by Kennison *et al*. (2009) and De Vries *et al*. (2016). There was one smoke treatment and two controls. In the *smoke treatments* (SM), the plots were isolated by plastic structures (five repeats) and subjected to a single hour-long treatment with smoke, as implemented by Sheppard *et al*. (2009). Similarly, in one of the controls, vine plots were isolated by greenhouse-type structures with no smoking (three repeats). There were only three *isolated control* (IC) repeats due to labour, time and cost constraints. In the other type of control, plots were left completely open (*open control* or OC), with five repeats. The use of an isolated-type control treatment offered a statistically sound alternative in the event that the open-type controls became contaminated. The control treatments, whether open or isolated, are referred to as 'unsmoked' in this study.

The structures were built from bamboo, lashed together with cable ties and covered with greenhouse-grade plastic. Selected fynbos (*Leucadendron salignum*, *Leucadendron spissifolium*, *Protea repens*) and pine (*Pinus radiata*) material was used to be representative of the flora found in the Western Cape. As a number of vineyards in the Western Cape border fynbos mountain regions (for example in Franschhoek, Stellenbosch and the Helderberg), these vineyards often are close to forestry plantations of pine (*Pinus radiata*). The pine was mixed in the *fynbos* in order to simulate potential fuel types under local conditions. This material was burned (25% m/v of each of the plant species) in a drum equipped with a blower to transfer the smoke into the structures and keep the fire alight. Treatments were carried out as a once-off, hour-long event ± 10 days' post-véraison. The structures were sealed for 24 hours post-treatment to simulate the lingering smoke and increased temperatures experienced during a natural fire event. The structures were then removed and the grapes were allowed to ripen before being harvested for vinification.

Winemaking

Wines were made for both the 2012 and 2013 vintages from the same treatment plots, following standard winemaking methods (De Vries *et al*., this issue). All wines were fermented to residual sugar levels below 2 g/L. The wine was left to settle, after which it was racked off the lees into clean 20 L stainless steel canisters. SO_2 was added at 50 mg/L in addition to 200 mL/hL of lysozyme (Lallzyme® Lyso-easy, Lallemand Inc., Montreal, Canada). The lysozyme and SO_2 additions were made in order to supress microbial activity and to reduce volatile phenol contamination from this source. The wines were then placed in a -4°C room for two weeks for cold stabilisation. After two weeks the wines were racked and free SO_2 levels were adjusted to 40 mg/L before bottling. The use of toasted oak wood chips or the ageing of wines in barrels may have contributed to the pool of free phenols (Carrillo & Tena, 2006), so the wines were not in contact with wood at any point during the study. The wine was filtered through a coarse mat filter with diatomaceous earth (previously sterilised) and transferred to 750 mL glass bottles (Consol Glass, RSA). Bottles were sealed with 'SAVin' (MCG Industries (Pty) Ltd., Paarden Eiland, RSA) aluminium screw-cap seals and stored at 15°C until evaluation.

The malic acid content was analysed post-bottling (WineScan FT 120 spectrometer) and the results indicated that the lysozyme and SO_2 additions during winemaking had inhibited the growth of spoilage yeast and lactic acid bacteria. Samples of all the experimental wines were analysed by SPME-GC-MS for volatile phenol content.

Sensory analyses

Wines from the 2012 vintage were evaluated in 2013 after a year in the bottle by 27 trained panellists – seven men and 20 women (aged 22 to 61, average age 29) – using a frequency-of-attribute citation method, pick-*K* attributes (Campo *et al*., 2008). The sensory judges were asked to select the three to five most prominent aroma attributes from a global list of terms. Additional DA (descriptive analysis) was conducted for taste attributes by rating intensities on a 10 cm unstructured line scale. Due to time constraints, wines from the 2013 vintage were not evaluated.

Panel training

The panellists received training on a list of aroma description terms, as well as basic taste attributes using reference standards. An initial list of terms was compiled based on the Pinotage aroma wheel (Marais & Jolly, 2004). Off-aromas such as 'tar' and 'band-aid' were also added to the list. An expert panel was employed to generate descriptors as a part of lexicon development for the specific set of wines to optimise the initial aroma descriptor list and ensure that important terms were not left out. The sensory training consisted of two stages – general training on aroma and taste

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attributes and specific training focusing on the specific set of wines to be evaluated, and finalising the lexicon to describe the samples. During general training, reference standards representative of aroma descriptors (Table 1) were presented in 50 mL amber glass bottles (Consol Glass, RSA).

The bottles containing the reference standards were wrapped in aluminium foil and a cotton wool swab was used to prevent tasters from visually inspecting the contents. For the first 40 minutes, panellists were allowed to familiarise themselves with the aromatic standards (Table 1) and specific wine lexicon (Table 2) used. The sensory standards used were then made known to the panellists. After a 10-minute break, the panellists were given taste standards and four commercial red wines to describe. Taste standards included solutions for astringency (0.5 g/L alum; Alpha Pharm, RSA) and bitterness (0.04 g/L quinine; Sigma-Aldrich) made up in water and in wine respectively. The panellists were then asked to describe commercial wines with the aid of the descriptor list and to rate astringency and bitterness on 10 cm unstructured line scales. To conclude the session, feedback was given on the descriptive terms most frequently cited by the panellists for each wine. During specific training, the panellists were trained with the experimental wines made for this study. During the final training session, wines were described using the global descriptor list. Descriptors cited by less than 20% of the panellists were removed from the list (Campo *et al*., 2008) to construct the final list used during testing (Table 2).

Sensory testing

Sensory analysis was done in a well-ventilated sensory laboratory with a constant temperature of 20°C (± 2°C). Each taster was served in an isolated booth. Wine samples of 25 mL were presented to the tasters in clear glasses (ISO NORM 3591, 1997). Black tasting glasses were not needed, as the colour difference between the wine treatments was not noteworthy. Glasses were covered with plastic petri dishes to allow for the equilibration of volatiles. The 13 wines were evaluated in duplicate over two sessions. Samples were marked with random three-digit codes and presented to the tasters in a unique serving order according to a Williams Latin-square design. In addition, the tasters were asked to take at least 15-second breaks between samples. The tasters were given water and crackers to cleanse their palate between samples or as needed to avoid carry-over effects related to astringency (Guinard *et al*., 1986).

Statistical analysis sensory data

Data generated using the pick-*K* attributes method was analysed as suggested by Campo *et al*. (2010), using R_i indices for individuals as a measure of their performance. Individuals with repeatability indices (R_i) < 0.2 were discarded from the data population, as suggested by Campo *et al*. (2010). The data generated was analysed by correspondence analysis (CA) to visualise differences and similarities between the samples. Hierarchical cluster analysis (HCA), using Euclidean distances and Ward's linkage, was used to identify groupings of similar samples on the CA plots.

The performance of the panel for DA was assessed according to the workflow, as suggested by Tomic *et al*. (2010); specifically, the repeatability of individual panellists and panel consensus were assessed. The data generated was analysed by analysis of variance (ANOVA) to determine which attributes were significant, and principal component analysis (PCA) was conducted using only the significant attributes.

Wine sensory data was analysed using Statistica 12, XLSTAT (V2013.05.04) and PanelCheck® (V1.4.0) software. PanelCheck® software was used to test panel performance of the DA data.

RESULTS AND DISCUSSION

Chemical analyses

Table 3 gives the volatile phenol content of the experimental wines from the 2012 vintage. This is discussed in detail in a concomitant study by the same researchers (De Vries *et al*., 2016).

Sensory evaluation

Sensory analysis of taste and mouthfeel attributes

Using PanelCheck® software, the panellists' performance (n = 27) was tested on astringency (mouthfeel), bitterness and 'ashy' flavour attributes. Sensory studies by Parker *et al*. (2012) describe an ash-like aftertaste from the presence of particularly guaiacol, 4-EG, *m*-cresol and their glycosidic forms when tasted in model wine. The same studies further showed that even below odour-threshold levels, these compounds led to this ashy flavour, suggesting an in-mouth release of bound phenol glycosides.

Panel testing was done with the 13 experimental (smoked and un-smoked) Cabernet Sauvignon wines. The panel showed consensus on all three taste attributes at a significance level of $p < 0.1\%$. The product effect test showed that both bitterness and astringency were not significant in the experimental Cabernet Sauvignon wines. An ANOVA analysis is thus not included for these two attributes. The 'ashy aftertaste' attribute was found to be significant, at a level of 0.002% (Fig. 1).

Previous studies (Kennison *et al*., 2007; Parker *et al*., 2012) have shown that the exposure of grapes to smoke leads to an unpleasant, ashy flavour in wines made from the affected grapes. Fig. 1 shows that the differences in treatment means are statistically significant at a 0.002% level. Post hoc testing using Fisher's LSD showed that differences with regard to ashy taste between the open control and isolated control treatments were not significant ($p = 0.89$). However, differences in ashy taste between wines from grapes exposed to smoke and those made from grapes from the open control and the isolated control treatments were significant ($p = 0.0013$ and $p = 0.0019$).

A concomitant study identifying and quantifying volatile phenols has shown that phenol, guaiacol, *o*-, *p*- and *m*-cresol were found to be significantly higher in Cabernet Sauvignon in wine made from grapes exposed to this smoke (De Vries *et al*., this issue). Parker *et al*. (2012) proved experimentally that *m*-cresol-β-D-glucoside and guaiacol-β-D-glucoside bring about an ashy, smoke-like flavour with a retronasal smell component when tasted in synthetic wine.

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TABLE 1
List of terms used for descriptive analysis and reference standards used during panel training.

Descriptive term	Odour reference (source/brand)	Formulation or concentration
Red berries		
Cherry	Cherry syrup (Védrenne)	5 mL of syrup in 15 mL of distilled water
Raspberry	Raspberry syrup (Vahiné)	5 mL of syrup in 15 mL of distilled water
Redcurrant	Redcurrants (Hillcrest Berries)	5 berries in 10 mL of distilled water
Strawberry	Strawberries (Hillcrest Berries)	½ strawberry in 10 mL of distilled water
Black berries/fruit		
Blackberry	Blackberries (Hillcrest Berries)	5 berries in 10 mL of distilled water
Blackcurrant	Blackcurrants (Hillcrest Berries)	5 berries in 10 mL of distilled water
Plum	Fresh plum	2 cm^3 plum in 10 mL of distilled water
Tropical fruits		
Banana	Fresh banana	1 cm^3 of banana in 10 mL of distilled water
Mango	Fresh mango + mango juice (Darling)	2 cm^3 of mango + 1 mL of mango juice in 10 mL distilled water
Dried fruit		
Prunes	Prunes (Safari)	1 prune finely chopped
Floral		
Violet	β-ionone (Sigma-Aldrich)	100 ng/L β-ionone in distilled water
Herbaceous		
Fynbos	Variety of collected fynbos	± 10 g of fynbos finely chopped
Rooibosch tea	Redbush tea (Freshpak)	Contents of 1 teabag in 10 mL of water
Tobacco	Cigarettes (Camel)	Contents of 1 cigarette
Menthol		
Eucalyptus	Fresh eucalyptus leaves	2 eucalyptus leaves chopped finely
Mint	Fresh mint (Allée Bleue)	2 mint leaves chopped finely
Spicy		
Aniseed	Aperitif anise (Carrefour)	10 drops of aperitif anise
Black pepper	Whole peppercorns (Robertsons)	2 peppercorns ground in a mortar and pestle
Cinnamon	Cinnamon powder (Robertsons)	0.05 g of cinnamon powder
Cloves	Clove powder (Robertsons)	0.05 g of clove powder
Liquorice	Liquorice (Mister Sweet)	2 cm^3 of liquorice
Nutmeg	Nutmeg powder (Robertsons)	0.03 g of nutmeg powder
Sweet–associated		
Fruitcake	Fruitcake (Pick n Pay)	3 cm^3 of fruitcake
Fruit conserve	Fruit conserve (Moir's)	3 cm^3 of crystallised fruit + 10 mL of hot water
Toffee	Toffee (Toffoluxe)	1.5 toffees in 10 mL of hot water
Savoury		
Savoury	Beef stock (Ina Paarman's)	2.5 g beef stock in 10 mL of hot water
Nutty		
Nutty	Peanuts (Safari)	5 whole peanuts ground in a mortar and pestle
Woody		
Coconut	Dried coconut (Imbo)	5 g + 10 mL of hot water
Oak wood	Toasted oak-wood chips (Radoux)	5 g of oak-wood chips
Vanilla	Vanilla essence (Vahiné)	½ teaspoon of vanilla essence in 10 mL of water
Toasted		
Chocolate	Cocoa powder (Moir's)	2 g cocoa powder in 10 mL of hot water
Coffee	Instant coffee (Jacobs)	1 g coffee in 10 mL of hot water
Earthy/animal		
Forest floor	Decayed leaf litter	± 10 g leaf litter
Horsy/barnyard	4-ethylphenol (Sigma-Aldrich)	700 µg/L in red wine
Medicinal/band-aid	Piece of plaster (Elastoplast®)	1 plaster cut up
Other		
Smoke	Burnt fynbos	± 10 g burnt fynbos
Tar/BR	Creosote	Wine soaked with a piece of tar-treated wood

TABLE 2
Final list of sensory terms used by the tasters and in the correspondence analysis (CA) and hierarchical cluster analysis (HCA) of the experimental wines.

Odour family	Descriptors used
Red berries	Red berries
Black berries	Black berries
Dried fruit	Prune
Tropical fruit	Banana
Menthol	Eucalyptus
Sweet associated	Toffee
Animal/other	Tar/BR, band-aid/medicinal, horsy/barnyard, smoke

TABLE 3
Post-bottling SPME-GC-MS chemical analysis of volatile phenols (in µg/L) of experimental wines prepared from grapes subjected to smoke treatments as well as wines prepared from grapes not subjected to smoke (control wines) during the 2012 vintage.

	Smoke treatment		
	Smoke	Open control	Isolated control
Guaiacol	8.62 (7.31) a	1.90 (0.45) b	1.99 (0.22) b
4-Methyl guaiacol	1.36# (0.72)	nd	nd
Phenol	27.99 (14.13) a	7.63 (0.73) b	7.36 (0.55) b
o-Cresol	6.01 (2.64) a	2.70 (0.39) b	3.09 (0.46) b
p-Cresol	4.21 (1.35) a	1.20 (0.10) b	1.41 (0.22) b
m-Cresol	3.32 (1.21) a	1.64 (0.20) b	1.70 (0.32) b
2,3-Xylenol	0.44 (0.10)	nd	nd
2,6-Xylenol	859.72 (52.19) a	832.69 (45.61) a	876.18 (77.06) a
Eugenol	1.52* (0.14)	1.50* (0.17)	1.38* (0.21)

*Values are means (SD) of quintuplicate analysis (open control and smoke treatments, n = 5) and triplicate analysis (open control, n = 3) letters denote differences in treatment means per vintage year at a 5% significance level
#Mean of two samples
nd = not detected

An in-mouth release of the free VP in combination with its glycoside is thought to be responsible for this specific taint flavour. Although phenolic glycosides were not tested in this study, the presence of free forms of *m*-cresol and guaiacol found in a concomitant chemical analysis of the samples (Table 3) could indicate that glycosidically bound forms also exist, leading to the ashy flavour perceived by the tasters.

Descriptive analysis of wine aroma attributes

Repeatability testing of the panellists' performance for the pick-*K* attributes sensory analysis showed that all panellists had repeatability indices > 0.4 (mean panel R_i of 0.5). Thus, 40% of the terms used by all the judges were common between the two replicates, with an average of 50% of terms used that were common. Panel performance was thus higher than the cut-off of (R_i) > 0.2 proposed by Campo *et al*. (2008). No data therefore was excluded based on poor panel performance.

The pick-*K* attributes data was organised into a contingency table and analysed by correspondence analysis (CA), as proposed by Campo *et al*. (2008). The CA analysis of frequency of citation data showed good distribution of the 13 experimental wines. Sensory repeats are indicated for each wine with a postscript, *e.g.* R1 or R2.

Agglomerated hierarchical cluster (AHC) analysis was used to interpret and classify data in the first and third dimensions of the CA plot into clusters. The dendrogram (Fig. 2) shows the responses generated by AHC analysis.

The most dissimilar responses and those most widely resolved were seen for wines made from smoked and

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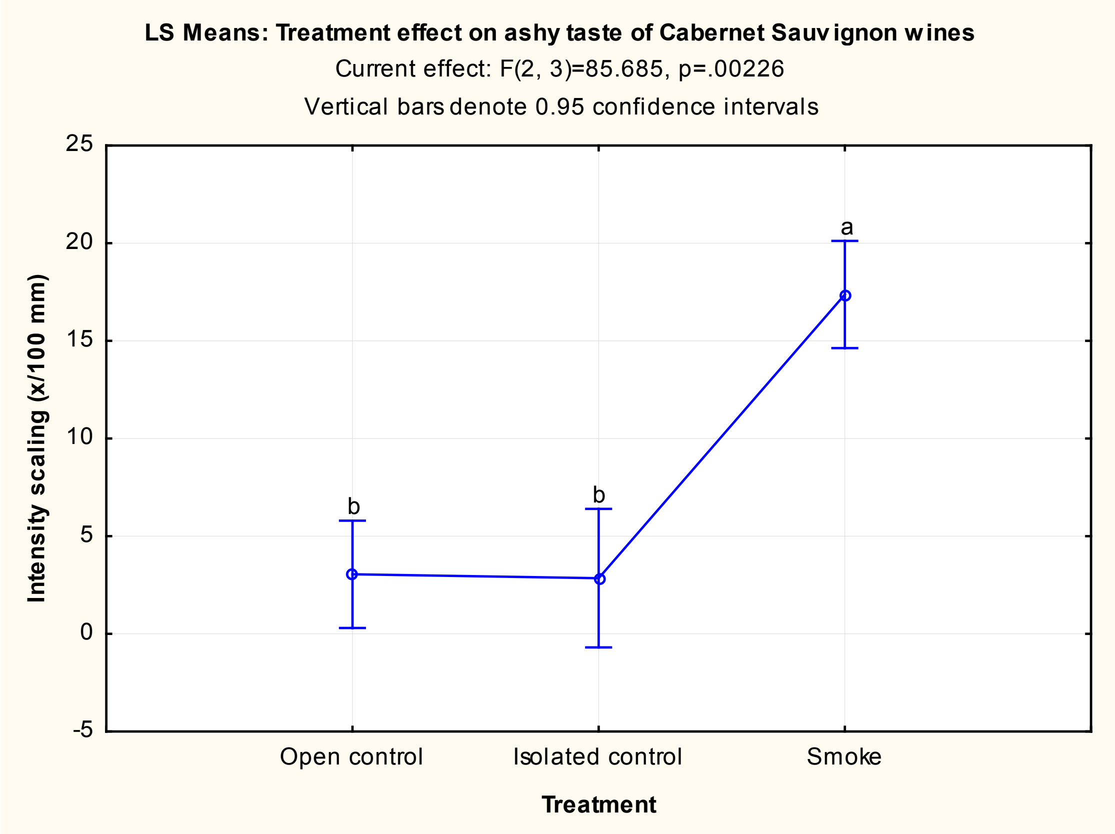

FIGURE 1
ANOVA least square means plot showing a significant difference in the ashy attribute in the 2012 experimental Cabernet Sauvignon wines.

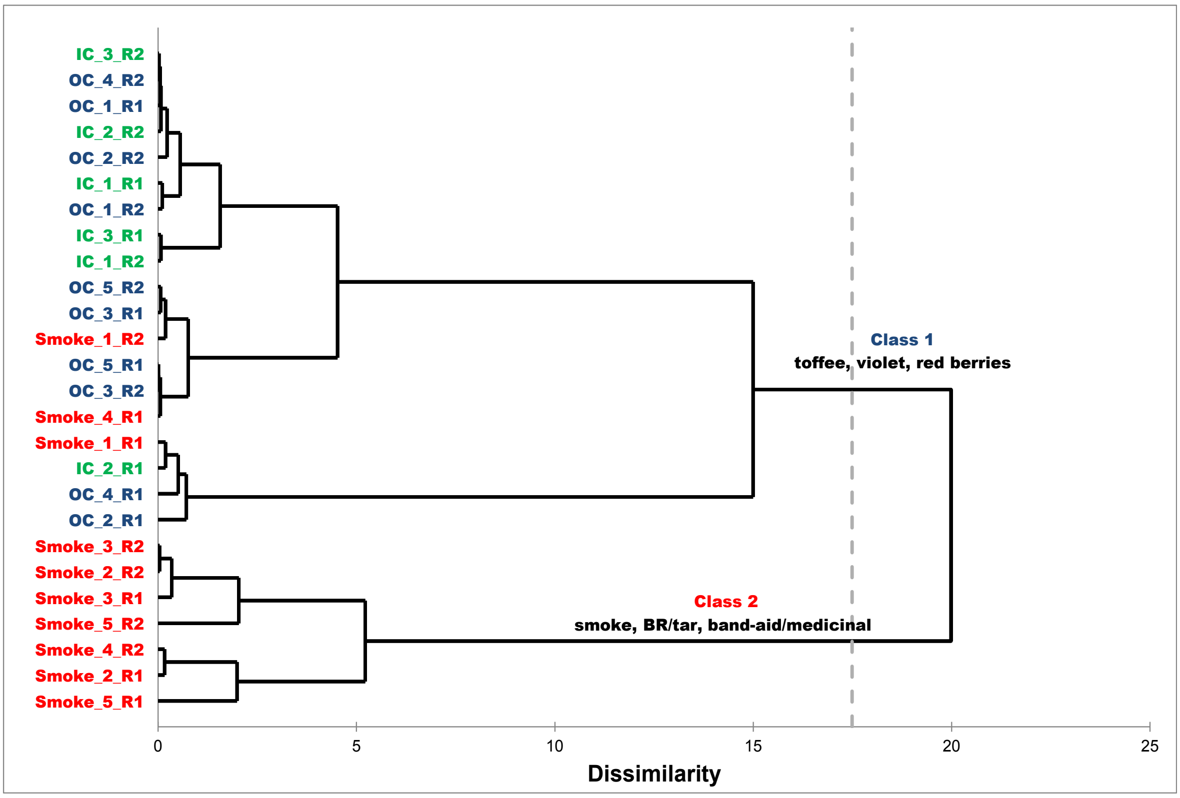

FIGURE 2
Dendrogram of responses generated by agglomerated hierarchical cluster (AHC) analysis of wine aroma data.

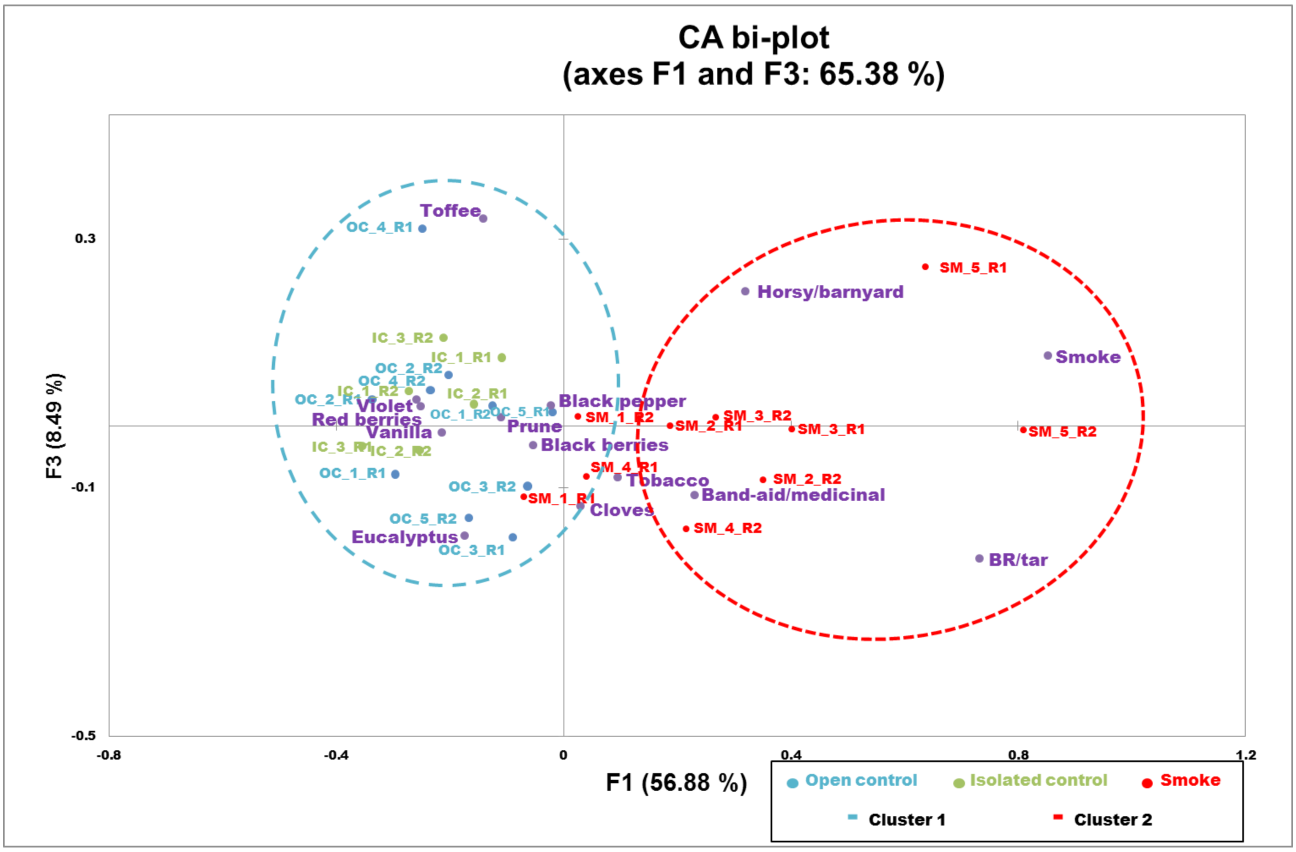

FIGURE 3

CA bi-plot of F1 against F3 showing clusters according to dissimilarity of responses found by AHC analysis.

unsmoked (open and isolated controls respectively) treatment plots. However, repeats of all wines were not grouped together. Wines from smoked and unsmoked plots showed similarities with alternate treatments that reduced resolution, as seen in Fig. 2 and Fig. 3. All repeats of unsmoked wines grouped together, with very low dissimilarity. Class centroids as determined by AHC gave the mean response for the coordinates in each cluster. The three descriptors cited most frequently by the tasters for class centroids (smoke, BR/tar, and band-aid/medicinal) were investigated (Fig. 3).

The class centroids are OC_2_R2 and Smoke_2_R2 for clusters 1 and 2 respectively. Attributes cited most frequently in class 1 (toffee, violet and red berries) can be seen as ‘clean’ when compared to the smoke, BR/tar, and band-aid/medicinal attributes in class 2.

The first two factor axes (F1 and F3) accounted for 65.38% of the data (Fig. 3). For the most part, wines made from untreated grapes (OC and IC) are well differentiated from smoke-treated wines along the first factor (F1). Areas of overlap occurred where some common attributes were cited for both smoked and un-smoked treatment wines. Attributes such as black pepper, black berries, cloves and tobacco were cited for both groups and thus reduce the dimensionality in factor 1. Experimental error during smoke treatments may also have had a role to play. During smoke treatments of the individual field repeats, the density of the smoke was not measured as in the study by Kelly *et al*. (2012), who used a laser nephelometer to regulate smoke density during the treatments. In the current study, smoke density was evaluated subjectively. The custom-made smoke generator may not have been smoking adequately when the first treatment repeat was done. This would explain why both sensory repeats for this wine (Smoke_1_R1 and Smoke_1_R2) are found in cluster 1, along with the unsmoked wines, as seen in Figs 2 and 3. The presence of one of the sensory repeats, ‘SM_4_R1’, in cluster 1 could indicate some uncertainty by the tasters during the first sensory repeat. In addition, 4-EG and 4-EP were only detected in the wine from smoke treatment plot SM_5. This would explain the differentiation of repeats of this wine relative to the other four smoked wines.

Most of the VPs were detected at concentrations below individual odour detection threshold levels (Table 4). Only guaiacol levels reached a concentration marginally higher than the 7.5 µg/L threshold reported for young red wines by Ferreira *et al*. (2000). This may account for the statistically significant ‘ashy’ taste that was found by the panel in all the smoke-affected samples. Good differentiation was observed between clean and smoke-affected samples during the orthonasal pick-*K* sensory analysis, despite levels being below or at detection thresholds, which may indicate that the compounds have a synergistic effect on odour and taste when in combination in solution (Panzeri, 2013). This aspect may form the subject of further research in the near future.

CONCLUSIONS

In this study it was found that Cabernet Sauvignon wines made from grapes exposed to smoke from burning a mixture of local Western Cape vegetation acquired ‘smoke taint’

TABLE 4
Aroma descriptors and odour detection threshold (OT) for volatile phenols in red wine.

Compound	Aroma descriptors	OT (µg/L)	Reference
Guaiacol	Smoke, sweet, medicinal	7.5[(1)]-23[(2)]	[(1)]Ferreira *et al*. (2000) [(2)]Parker *et al*. (2012)
4-Methyl guaiacol	Ashy, toasted	65	Kennison *et al*. (2009)
Phenol	Sickeningly sweet[(3)], irritating	7 100*	Parker *et al*. (2012)
***o*-Cresol**	Band-aid, medicinal, smoky	62	Parker *et al*. (2012)
***p*-Cresol**	Band-aid, phenol-like	64	Parker *et al*. (2012)
***m*-Cresol**	Dry, tarry, medicinal-leathery	20	Parker *et al*. (2012)
2,3-Xylenol	Phenolic	500**	Verschueren (1983)
2,6-Xylenol	Medicinal, phenolic	570*	Escudero *et al*. (2007)
Eugenol	Clove	6*	Escudero *et al*. (2007)

*OT measured in synthetic wine, **OT measured in water
[1]OT as published in Ferreira *et al.* (2002)
[2]OT as published in Parker *et al*. (2012)
[3]The attribute sickly sweet was only published in Panzeri (2013)

(a negative, burnt, smoky aroma) that could be perceived sensorially by a trained panel, despite the fact that the treatment was only a single, hour-long application at 10 days' post-véraison. No taint was detected in wines made from unexposed grapes.

The levels of free VPs in the wines were analysed by GC-MS in a simultaneous study and were found to be below or very close to the published odour threshold levels for individual phenols. Despite the low levels, wines made from smoke-exposed grapes still exhibited taint characteristics. It was also found that smoke exposure may contribute to the so-called 'burnt rubber' taint perceived in some South African red wines, as aroma attributes frequently cited and significant for the smoke-affected wines included the terms 'burnt-rubber/tar' and 'band-aid/medicinal'. The full contribution to the aroma profile of free forms and bound, non-volatile phenolic glycosides that might have been released during wine maturation and the ageing of the wines was not analysed, but as the wines from the 2013 vintage are still available, this may be the subject of an additional sensory study Furthermore, the release of volatiles from glycosidic precursors in wines from the 2016 vintage by acidic and enzymic hydrolysis will also form the subject of a future study. It would be interesting to see if an untrained panel, such as a regular consumer panel, would perceive differences between wines made from smoke-affected and control grapes, and what the impact would be on the liking and acceptability of the wines.

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